APPARATUS FOR CONSERVING VAPOR IN A CARBON DIOXIDE DRY CLEANING SYSTEM

Related Applications

This application is a divisional of and claims priority from U.S. Patent Application No. 10/044,382, filed January 11, 2002, which is a divisional of and claims priority from U.S. Patent Application No. 09/404,957, filed September 24, 1999, now U.S. Patent No. 6,397,421, issued June 4, 2002, the disclosures of which are incorporated by reference herein in their entireties.

Field of the Invention

This invention relates to methods and apparatus for conserving vapor and collecting liquid carbon dioxide for cleaning systems, more particularly to methods and apparatus for conserving vapor and collecting liquid carbon dioxide for carbon dioxide dry cleaning systems.

Background of the Invention

Organic solvents such as perchloroethylene and other low-pressure liquid solvents have long been popular for use in cleaning systems such as dry cleaning systems. Recently, however, there are growing concerns that these solvents may harm the environment and pose occupational safety hazards. These concerns have led to an extensive search for alternative solvents that are less hazardous and systems for applying such solvents.

Some of this research has focused on systems utilizing solvents that are gases at low pressure. These systems may operate either under subcritical conditions such that the solvent is present as a liquid or under supercritical conditions such that the solvent is present as a supercritical fluid. Some of these systems utilize liquid carbon dioxide (CO_2) as a cleaning solvent.

PCT Publication WO 99/13148 to Shore et al. describes a cleaning system using liquid CO_2. Shore describes evacuating a cleaning chamber to remove air from the chamber. Shore also discusses filling the chamber with carbon dioxide gas from either a distillation vessel or a liquid CO_2 storage tank as part of a prefill mode. Shore further describes how draining liquid carbon dioxide from the cleaning chamber leaves carbon dioxide gas in the chamber and discusses an apparatus for reclaiming this gas using a compressor and a condenser to return reliquified CO2 to a liquid storage tank.

The system described by Shore is inefficient making it expensive to operate and expensive to construct. For example, filling the cleaning chamber with CO2 gas from a distillation vessel requires that a distillation vessel be supplied and operated. Alternatively, using vaporization of the liquid CO2 in the storage tank requires the storage tank to contain a heater sized to provide make-up heat equal to the heat of vaporization of the liquid CO2 that is converted to vapor.

Furthermore, a condenser must be supplied which is sized to handle the extreme vapor loads experienced at the beginning of the vapor reclamation step. Additionally, cooling must be supplied to this condenser. Other methods for removing the CO2 gas from the cleaning chamber such as venting to atmosphere, which results in loss of CO2 from the system, or sparging as described in PCT Publication WO 97/33031 to Taricco are similarly inefficient.

A small amount of air in the system may be beneficial, providing a partial pressure in the liquid CO2 storage tank and resulting in increased net positive suction head for the pump. However, the efficiency of the condenser can be drastically affected by even small amounts of air. Thus, a vacuum pump must be operated before each cycle to ensure that all air has been evacuated from the cleaning chamber.

Further inefficiencies occur in carbon dioxide cleaning systems that employ cleaning solutions comprising liquid carbon dioxide and other additives or detergents. To create a source of liquid CO2, these systems rely on evaporators or stills to separate additives and contaminants from the cleaning solution and generate CO2 vapor. Such stills and evaporators require heating elements, which must be sized to supply sufficient CO2 vapor and operated using steam or electricity.

Summary of the Invention

It is therefore an object of the present invention to provide methods and apparatus for improving the thermodynamic efficiency of a liquid carbon dioxide dry cleaning system.

It is another object of the present invention to provide methods and apparatus for lowering the capital costs associated with a liquid carbon dioxide dry cleaning system.

These and other objects are provided, according to the present invention, by an apparatus for conserving carbon dioxide vapor in a carbon dioxide dry cleaning system employing a liquid carbon dioxide cleaning solution to clean articles, where the apparatus includes a wash tank for contacting the articles to be cleaned with the liquid carbon dioxide cleaning solution, a working tank for storing liquid carbon dioxide cleaning solution, a vapor tank for storing carbon dioxide vapor, a first piping system providing fluid communication between the wash tank and the vapor tank where the first piping system includes a first line and a first valve residing in the first line, and a second piping system providing fluid communication between the working tank and the wash tank.

According to the present invention, the first valve may be sized to limit vapor flow rate through the first line.

In a preferred embodiment, the apparatus includes a compressor for transferring carbon dioxide vapor between the wash tank and the vapor tank, where the compressor resides in the first piping system, a third piping system providing fluid communication between the working tank and the first piping system, and a condenser for condensing carbon dioxide vapor to liquid carbon dioxide, where the condenser resides in the third piping system.

According to the present invention, a method for conserving carbon dioxide vapor in a carbon dioxide dry cleaning system employing a liquid carbon dioxide cleaning solution to clean articles may also be employed, which includes removing carbon dioxide vapor from a wash tank to a vapor tank, storing the carbon dioxide vapor in the vapor tank and charging the wash tank with carbon dioxide vapor from the vapor tank. By conserving the carbon dioxide vapor, a condenser may not be needed, which may reduce or eliminate the need to remove air from the system at the

beginning of each wash cycle. Thus, the need for a vacuum pump may be reduced or even eliminated resulting in lower capital costs and operating expenses. Furthermore, higher concentrations of air in the system may increase the efficiency of the system by providing a partial pressure in the head-space of the working tank, resulting in increased net positive suction head for a pump.

In a preferred embodiment, removing carbon dioxide vapor from a wash tank to a vapor tank includes transferring carbon dioxide vapor from the wash tank having a higher pressure to the vapor tank having a lower pressure utilizing a piping system, pumping the carbon dioxide vapor out of the wash tank using a compressor when the differential pressure between the wash tank and the vapor tank is less than about 100 psig, condensing a portion of the carbon dioxide vapor into liquid carbon dioxide in a condenser, storing the liquid carbon dioxide in a working tank, stopping the compressor when the pressure in the wash tank is less than about 100 psig, and venting carbon dioxide from the wash tank to atmosphere. Charging the wash tank with carbon dioxide vapor from the vapor tank includes transferring carbon dioxide vapor from the vapor tank having a higher pressure to the wash tank having a lower pressure utilizing a piping system, pumping the carbon dioxide vapor out of the vapor tank using a compressor when the differential pressure between the vapor tank and the wash tank is less than about 100 psig, generating carbon dioxide vapor in a working tank, stopping the compressor when the pressure in the wash tank is less than about 50 psig, and venting carbon dioxide from the wash tank to atmosphere.

By condensing only a portion of the carbon dioxide vapor, the size of the condenser may be reduced resulting in lower capital costs and the heat removed from the condenser may be reduced resulting in increased thermodynamic efficiency.

According to the present invention, an apparatus may also be employed for collecting liquid carbon dioxide in a carbon dioxide dry cleaning system employing a liquid carbon dioxide cleaning solution to clean articles, where the apparatus includes a vapor tank, a condenser, a working tank containing carbon dioxide cleaning solution, a wash tank, a liquid carbon dioxide collecting tank, a first piping system providing fluid communication between the condenser, the working tank, and the liquid carbon dioxide collecting tank, a second piping system providing fluid communication between the liquid carbon dioxide collecting tank and the wash tank,

and a third piping system providing fluid communication between the wash tank and the vapor tank.

According to the present invention, a method may also be employed for supplying a liquid carbon dioxide solution to a wash tank for a carbon dioxide dry cleaning system, utilizing a vapor tank, a condenser, a liquid carbon dioxide collecting tank, a working tank containing carbon dioxide cleaning solution, and a wash tank, where the method includes draining a solution comprising liquid carbon dioxide from the wash tank leaving carbon dioxide vapor in the wash tank, transferring the carbon dioxide vapor from the wash tank to a vapor tank, condensing a portion of the carbon dioxide vapor transferred to the vapor tank to form liquid carbon dioxide, collecting the liquid carbon dioxide in the liquid carbon dioxide collecting tank, and draining the contents of the liquid carbon dioxide collecting tank into the wash tank. By conserving the carbon dioxide vapor left in the wash tank after draining a solution comprising liquid carbon dioxide, transferring this vapor from a wash tank to a vapor tank, and condensing a portion of this conserved carbon dioxide vapor to form liquid carbon dioxide rather than generating carbon dioxide vapor in an evaporator or the like, the need for an evaporator and like equipment may be reduced or eliminated, which may reduce capital and operating costs and may improve the thermodynamic efficiency of the cleaning system.

In a preferred embodiment, the method includes rinsing articles in the wash tank with liquid carbon dioxide after the draining step and emptying the contents of the wash tank into the working tank.

In yet another preferred embodiment, the method includes injecting additives into the liquid carbon dioxide collecting tank to form a filter wash solution after the collecting step and before the draining step, washing at least one filter with the contents of the liquid carbon dioxide collecting tank after the draining step, and emptying the wash tank.

Methods and apparatus according to the present invention may therefore improve the thermodynamic efficiency of and reduce the capital costs associated with a liquid carbon dioxide dry cleaning system. It will be understood that the present invention may be embodied as methods and apparatus and combinations thereof.

Brief Description of the Drawings

Figure 1 illustrates a carbon dioxide dry cleaning system employing a vapor tank according to the present invention.

Figure 2 illustrates a carbon dioxide dry cleaning system employing a vapor tank and a liquid carbon dioxide collecting tank according to the present invention.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

Referring first to Figure 1, a wash cycle will be described, focusing particularly on charging carbon dioxide vapor into and removing carbon dioxide vapor from wash tank **154**. In general, a wash cycle may be performed in the following steps: (1) placing clothes to be cleaned into wash tank **154**; (2) charging carbon dioxide vapor into wash tank **154** to pressurize it; (3) transferring liquid cleaning solution, comprising liquid carbon dioxide as a solvent, from working tank **153** to wash tank **154** via pump **155**; (4) washing clothes in wash tank **154**; (5) draining liquid cleaning solution from wash tank **154** and transferring liquid cleaning solution via pump **155** back to working tank **153**; (6) extracting remaining liquid cleaning solution from clothes in wash tank **154**; (7) removing carbon dioxide vapor from wash tank **154** to depressurize it; and (8) removing clean clothes from wash tank **154**. For illustrative purposes, this description will begin in the middle of a wash cycle, at the washing step, and end at the washing step in the next wash cycle. Valves **101-115** are shut, compressor **152** and pump **155** are secured, and system pressure and temperature are at or near saturated conditions for the given cleaning solution, preferably between about 55 to 62°F (10 to 17°C) at between about 681 to 756 psig for a carbon dioxide based system. One who is skilled in the art will understand that carbon dioxide dry cleaning systems can be operated at a variety of pressures and temperatures.

After washing clothes in wash tank **154** for a sufficient amount of time, the liquid cleaning solution may be drained from wash tank **154** by opening valves **109, 110, 111, 101,** and **105** starting pump **155**, which transfers the liquid cleaning solution from wash tank **154** through lines **135, 134,** and **133** back to working tank **153**. Once the liquid cleaning solution is transferred, pump **155** is secured and valves **109, 110, 111, 101,** and **105** are shut. One who is skilled in the art will appreciate that lines may be selected from a group comprising piping, conduit, and other means of fluid communication that can withstand system temperature and pressure. Piping for the system is preferably schedule 40, stainless steel, and conforms to ANSI standards B31.3. One who is skilled in the art will also understand that a piping system may be comprised of one or more lines and that zero or more valves may reside in the one or more lines.

Any remaining liquid cleaning solution may be mechanically or otherwise extracted from the clothes in wash tank **154**, and the remaining liquid cleaning solution may be drained from wash tank **154** using the drain procedure outlined above. At this point, the atmosphere in wash tank **154** is comprised primarily of carbon dioxide vapor.

Once the liquid cleaning solution has been drained, the carbon dioxide vapor in wash tank **154** may be removed to a vapor tank as follows, depressurizing wash tank **154** and allowing clean clothes to be removed. Valves **101** and **104** are opened, allowing the carbon dioxide vapor to move from wash tank **154** through lines **124** and **122** to vapor tank **150**. Vapor tank **150** preferably has a volume of about 6 to about 60 ft^3 (about 0.17 to about 1.7 m^3). One skilled in the art will be able to select appropriate tanks to withstand system pressure and temperature by using, for example, the ASME Pressure Vessel Code. Valve **101** and line **124** may be sized to provide adequate restriction to the vapor flow to limit the velocity of this gas stream when the differential pressure between wash tank **154** and vapor tank **150** is at its greatest, about 700 psig or greater. Valve **101** is preferably a 1/2" full-flow ball valve, model #8450 commercially available from Watts Regulator Company of N. Andover, MA. Line **124** is preferably a 1" schedule 40, stainless steel pipe conforming to ANSI standards B31.3. One who is skilled in the art could select a suitable valve to limit the flow rate resulting from other pressure differentials.

When this differential pressure has been reduced sufficiently, preferably less than 200 psi differential, valves **102** and **103** may be opened to facilitate vapor transfer by providing an additional flow path through lines **123** and **121**. When the pressure differential between wash tank **154** and vapor tank **150** has been reduced such that it is less then about 100 psig, preferably less than about 50 psig, more preferable at or near zero, valves **101** and **103** are shut and compressor **152** is started. Compressor **152** pumps carbon dioxide vapor from wash tank **154** through lines **123**, **121**, and **122** to vapor tank **150**. When the pressure in wash tank **154** is at or near atmospheric pressure, preferably less than about 100 psig, more preferably less than about 50 psig, compressor **152** is secured and valves **102** and **104** are shut. Any vapor remaining in wash tank **154** may be vented through valve **113**. Wash tank **154** is now depressurized and clean clothes may be removed from it.

As just described, draining a solution comprising liquid carbon dioxide out of wash tank **154** may result in carbon dioxide vapor remaining in wash tank **154**. Removing most if not all of this carbon dioxide vapor to a vapor tank rather than condensing it to liquid carbon dioxide conserves the carbon dioxide vapor for reuse in charging wash tank **154** at the beginning of a cycle. Thus, use of the vapor tank may eliminate the need for a condenser and may reduce the capital and operating costs of the cleaning system. Furthermore, conserving the carbon dioxide vapor for reuse in charging the wash tank at the beginning of a cycle may improve the thermodynamic efficiency of the system. Additionally, which may reduce or eliminate the need to remove air from the system at the beginning of each wash cycle. Thus, the need for a vacuum pump may be reduced or even eliminated resulting in lower capital costs and operating expenses. Furthermore, higher concentrations of air in the system may increase the efficiency of the system by providing a partial pressure in the head-space of the working tank, resulting in increased net positive suction head for a pump.

While compressor **152** may be used to remove all or almost all of the carbon dioxide vapor from wash tank **154** as just described, this process may be somewhat inefficient. As the pressure in vapor tank **150** builds, the compressor **152** reaches high compression ratios and the vapor transfer rate through compressor **152** decreases. Thus, compressor **152** may have to run for a long time to remove all or nearly all of the vapor from wash tank **154**, resulting in energy and time inefficiencies. The vapor

removal step described above may be augmented to utilize condenser **151**, partially if not completely eliminating these inefficiencies by reducing the pressure in vapor tank **150** as follows. When the pressure differential between wash tank **154** and vapor tank **150** has been reduced sufficiently, preferably less than about 100 psig, more preferably less than 50 psig, most preferably at or near zero, valves **101** and **104** are shut and compressor **152** is started. Valve **114** is opened and condenser **151** is brought on-line. The remaining vapor in wash tank **154** is transferred through lines **123**, **121**, and **122** to vapor tank **150**. Valve **105** is opened and some of the vapor flowing through line **122** begins to flow through line **127**, condense in condenser **151**, and flow as liquid through line **128** into working tank **153**. When the pressure in wash tank **154** is at or near atmospheric pressure, preferably less than about 100 psig, most preferably less than about 50 psig, compressor **152** is secured and valves **102**, **104**, **105**, and **114** are shut. Any vapor remaining in wash tank **154** may be vented through valve **113**. Wash tank **154** is now depressurized and clean clothes may be removed from it.

A condenser must be sized to provide sufficient cooling during peak load conditions. By utilizing condenser **151** to condense only a portion of the carbon dioxide vapor removed from wash tank **154** rather than all or almost all of the vapor, the size of condenser **151** may be drastically reduced because the peak load experienced by the condenser has been drastically reduced. This embodiment may therefore result in lower capital and operating costs.

As carbon dioxide vapor is removed from wash tank **154** as described above, the temperature within wash tank **154** may decrease as the vapor expands. This temperature decrease may cause frozen carbon dioxide, commonly known as dry ice, to form on the clothes in wash tank **154**. To reduce or eliminate this cooling effect, it may be desirable to heat the contents of wash tank **154** as the vapor is removed. Heat is preferably supplied using heating element **156** by opening valve **115**; however, one skilled in the art will know other ways of providing heat to wash tank **154**.

At the beginning of the next wash cycle, clothes to be cleaned may be placed into wash tank **154**, which is at atmospheric pressure. As mentioned above, the cleaning solution in working tank **154** is at or near saturated conditions, preferably between about 55 to 62°F (10 to 17°C) at between about 681 to 756 psig for a carbon

dioxide based system. The pressure differential between working tank **153** and wash tank **154,** roughly 700 psig, may be reduced to facilitate safely transferring liquid cleaning solution to wash tank **154** by charging conserved carbon dioxide vapor from vapor tank **150** into wash tank **154** to pressurize it.

Wash tank **154** may be pressurized by charging the conserved carbon dioxide vapor from vapor tank **150** to wash tank **154** as follows. Valves **104** and **101** are opened, allowing vapor to move from vapor tank **150** through lines **122** and **124** to wash tank **154**. Valve **101** and line **124** may be sized to provide adequate restriction to the vapor flow to limit the velocity of this gas stream when the differential pressure between vapor tank **150** and wash tank **154** is at its greatest. When this differential pressure has been reduced sufficiently, preferably less than 200 psi differential, valves **103** and **102** may be opened to facilitate vapor transfer by providing an additional flow path through lines **121** and **123**. When the pressure differential between wash tank **154** and vapor tank **150** has been reduced such that it is at or near zero, valves **104** and **102** are shut and compressor **152** is started. Compressor **152** pumps conserved carbon dioxide vapor from vapor tank **150** through lines **121**, **121**, and **124** to wash tank **154** until the differential pressure between working tank **153** and wash tank **154** has been reduced such that it is less than about 300 psig, preferably less than 200 psig, more preferably less than or equal to 100 psig. Then, compressor **152** is secured and valves **103** and **101** are shut. Alternatively, only valve **101** could be shut, keeping valve **103** open and compressor **152** running to facilitate transfer of cleaning solution from the working tank **153** to wash tank **154** as described below. Wash tank **154** has now been pressurized such that the differential pressure between wash tank **154** and working tank **153** is at or near zero and cleaning solution may be transferred safely from working tank **153** to wash tank **154**.

Charging conserved carbon dioxide vapor from vapor tank **150** to wash tank **154** rather than generating vapor by vaporizing cleaning solution in an evaporator, still, or storage tank may eliminate the need for an evaporator, a still, or a heating element in the storage tank. Thus, the present invention may reduce capital costs and operating expenses and may be more thermodynamically efficient.

While compressor **152** may be used to pump the remaining conserved carbon dioxide vapor from vapor tank **150** to pressurize wash tank **154** as just described, this

process may be somewhat inefficient. As the pressure in wash tank **154** builds, the compressor **152** reaches high compression ratios and the vapor transfer rate through compressor **152** decreases. Thus, compressor **152** may have to run for a long time to pressurize wash tank **154** completely or nearly completely, resulting in energy and time inefficiencies. The vapor charging step described above may be augmented as follows, partially if not completely eliminating these inefficiencies. When the pressure differential between wash tank **154** and vapor tank **150** has been reduced such that it is at or near zero, valves **104** and **102** are shut and compressor **152** is started. Compressor **152** pumps conserved carbon dioxide vapor from vapor tank **150** through lines **121**, **121**, and **124** to wash tank **154**. When compressor **152** begins to reach high compression ratios, valve **105** is opened. Vapor pressure in working tank **153** drops and cleaning solution in working tank **153** begins to boil. Vapor from working tank **153** flows through line **128**, through condenser **151** which is off-line, and through line **127** where this vapor joins the flow of vapor in line **122** coming from the compressor **152** and flows into the wash tank through line **124**. When the differential pressure between working tank **153** and wash tank **154** has been reduced such that it is at or near zero, compressor **152** is secured and valves **103**, **105**, and **101** are shut. Wash tank **154** has now been pressurized such that the differential pressure between wash tank **154** and working tank **153** is at or near zero and cleaning solution may be transferred safely from working tank **153** to wash tank **154**.

By supplying only a portion rather than all of the carbon dioxide vapor by vaporizing the cleaning solution in working tank **153**, the heat that must be supplied to the cleaning solution to make-up for heat lost due to vaporization may be reduced. Thus, the present invention may reduce capital costs and operating expenses and may be more thermodynamically efficient.

Cleaning solution may be transferred from working tank **153** to wash tank **154** by opening valves **112**, **110**, **108**, **101**, and **105** and starting pump **155**. Cleaning solution moves from working tank **153** through lines **136**, **135**, **134**, and **132** into wash tank **154**. When a sufficient amount of cleaning solution has been transferred, pump **155** is secured and valves **112**, **110**, **108**, **101**, and **105** are shut. While cleaning solution is being transferred from working tank **153** to wash tank **154**, the pressure in vapor tank **150** may be reduced by opening valves **103** and **105**, bringing condenser

151 on-line by opening valve **114** and starting compressor **152**. This pressure may be reduced to better prepare vapor tank **150** to receive vapor during the next cycle. When pressure in vapor tank **150** has been reduced to preferably less than 100 psig, most preferably less than 50 psig, compressor **152** is secured and valves **103, 105**, and **114** are shut.

Alternatively, cleaning solution may be transferred using compressor **152** instead of pump **155**. To accomplish this transfer, compressor **152** is allowed to continue running after the differential pressure between vapor tank **150** and wash tank **154** has been reduced such that it is at or near zero. When the outlet pressure of compressor **152** is slightly higher than the pressure in working tank **153**, valve **101** is shut and valve **105** is opened such that the outlet pressure from compressor **152** pressurizes the vapor space in working tank **153**. Of course, condenser **151** is not providing cooling to the vapor in line **127** because valve **114** is closed. With working tank **153** now under additional pressure, valves **112** and **111** are opened. Cleaning solution is transferred from working tank **153** to wash tank **154** through lines **136** and **135**. When a sufficient amount of cleaning solution has been transferred, compressor **152** is secured and valves **112, 111, 105**, and **103** are shut. Washing clothes in wash tank **154** is commenced.

Similarly, solution may be transferred from wash tank **154** to working tank **153** using the compressor. Vapor from vapor tank **150** may be transferred to wash tank **154** to raise the pressure in wash tank **154** above that of working tank **153** by opening valves **103** and **101** and starting compressor **152**. Solution may then be transferred from wash tank **154** to working tank **153** by opening valves **111** and **112**. When the desired amount of solution has been transferred, valves **111** and **112** may be shut, compressor **152** may be secured, and valves **101** and **103** may be shut.

In an alternative embodiment, two dry cleaning systems may be interconnected such that vapor tank **150** is a wash tank for a second system, which may have its own compressor, condenser, pump, and working tank, or preferably share some or all of these components with the first system. When wash tank **150** in the first system is depressurized as described above, the conserved carbon dioxide vapor pressurizes the wash tank in the second system. Thus, these two systems may work together such that the wash cycles are 180° out of phase. For example, when

one system is contacting clothes with cleaning solution, the wash tank in the other system may be emptied.

The temperature of the system may increase for a number of reasons, including, but not limited to, heat input from pumping cleaning solution, heat input from ambient and heat input from warming clothes in wash tank **154**. It may be desirable to cool down the system for several reasons including maintaining optimal system conditions and preventing overpressure.

Cleaning solution in wash tank **154** may be cooled by transferring vapor from wash tank **154** to condenser **151**, condensing the vapor there, and transferring the liquid carbon dioxide to working tank **153**. Transferring vapor from wash tank **154** may cause the pressure in wash tank **154** to drop slightly, which may cause vaporization of some of liquid cleaning solution, resulting in removal of heat due to the heat of vaporization of the boiled liquid. The quantity of vapor transferred may be small enough that the differential pressure between wash tank **154** and condenser **151** should provide sufficient driving force to move the vapor. Additionally, the quantity of cleaning solution vaporized may be small enough that no cleaning solution need be added back to the wash tank. Vapor may be transferred by opening valves **101**, **105**, and **114** causing vapor to flow through lines **124**, **122**, and **127**, condense in condenser **151**, and flow as liquid through line **128** into working tank **153**. When the solution in wash tank **154** has been sufficiently cooled, valves **101**, **105**, and **114** may be shut.

Similarly, cleaning solution in working tank **153** may be cooled by transferring vapor from working tank **153** to condenser **151**, condensing the vapor there, and returning the liquid carbon dioxide to working tank **154** as follows. Valve **114** may be opened, bringing condenser **151** on-line and allowing vapor in line **128** to condense. When the solution in working tank **153** has been sufficiently cooled, valve **114** may be shut.

Alternatively, vapor from wash tank **154** may be transferred to vapor tank **150**, which may be maintained at a pressure sufficiently below the pressure of wash tank **154** such that the pressure differential between the two tanks drives vapor flow. During a wash cycle, vapor tank **150** is preferably maintained at a pressure less than about 300 psig. Vapor transfer may be performed by opening valves **101** and **104**.

When the cleaning solution in wash tank **154** reaches the desired temperature, valves **101** and **104** can be shut. The vapor thus transferred may be transferred to condenser **151** using compressor **152** and the resulting liquid carbon dioxide returned to working tank **153** by opening valves **103**, **105**, and **114** and starting compressor **152** causing vapor to flow through lines **121**, **123**, **121**, **122**, and **127**, condense in condenser **151** and flow as liquid through line **128** into working tank **153**. When the desired amount of vapor has been transferred compressor **152** can be secured and valves **103**, **104**, and **114** shut.

Similarly, vapor may be transferred from working tank **153** to vapor tank **150** to provide desired cooling to solution in working tank **153** as follows. With valve **114** shut, such that condenser **151** is off-line, valves **105** and **104** may be opened, transferring vapor from working tank **153**, which is at a higher pressure, to vapor tank **150**, which is at a lower pressure. Preferably, working tank **153** is at system pressure described above and vapor tank is at a pressure less than system pressure, preferably less than 500 psig, more preferably less than 300 psig. Transferring vapor from working tank **153** may cause the pressure in working tank **153** to drop slightly, which may cause vaporization of some of the liquid cleaning solution, resulting in removal of heat due to the heat of vaporization of the boiled liquid. This vapor may be condensed and returned to the working tank as described above.

Referring now to Figure 2, a carbon dioxide dry cleaning system employing a vapor tank and a liquid carbon dioxide collecting tank will now be described. Valves **201-215**, lines **225-241**, and equipment **250-253** correspond to valves **101-115**, lines **120-136**, and equipment **150-156** in Figure 1. Additionally, a wash cycle for the system shown in Figure 2 occurs as described above for the system shown in Figure 1.

Liquid carbon dioxide collecting tank **259** collects liquid CO_2, which may then be used in a variety of ways described below. Liquid carbon dioxide collecting tank **259** has an inlet line **229** and an outlet line **231**. Inlet line **229** is connected to line **228**, the outlet to condenser **251**, such that when liquid flows through line **228** from condenser **251** to working tank **253**, the liquid is diverted to liquid carbon dioxide collecting tank **259**. Outlet line **231** runs between liquid carbon dioxide collecting tank **259** and wash tank **254**. In a preferred embodiment, the elevation of liquid carbon dioxide collecting tank **259** is higher than that of wash tank **254** such that fluid

in liquid carbon dioxide collecting tank **259** may be gravity fed through line **231** into wash tank **254** by opening valves **206, 205**, and **201**. Liquid carbon dioxide collecting tank **259** should have a sufficient volume to perform desired procedures such as rinsing the contents of wash tank **254** or washing filter **257**. Liquid carbon dioxide collecting tank preferably has a capacity of about 5 to about 30 gallons and more preferably has a capacity of about 5 to about 15 gallons. When liquid carbon dioxide collecting tank **259** is full, its excess contents may spill out through lines **229** and **228** into working tank **253**.

Liquid carbon dioxide collecting tank **259** may be filled with liquid CO_2 from a number of different sources either individually or in combination including the following. One source of liquid CO_2 may be working tank reflux. The cleaning solution in working tank **253** may heat up due to heat transfer into the tank from higher ambient temperatures. If this happens, the cleaning solution may begin to boil. Vapor will travel from the vapor space in working tank **253** through line **228** into condenser **251**. When valve **214** is open and condenser **251** is on-line, the vapor condenses and flows back down line **228** as liquid CO_2. This liquid CO_2 will flow through line **229** into liquid carbon dioxide collecting tank **259**. Another source of liquid CO_2 may be the CO_2 that condenses during the vapor removal step described above for the system in Figure 1 where valve **214** is opened and condenser **251** is brought on-line, valve **205** is opened and some of the vapor flowing through line **222** begins to flow through line **227**, condense in condenser 251, and flow as liquid through line **228**. This liquid CO_2 flows into liquid carbon dioxide collecting tank **259**. Yet another source of liquid CO_2 may be CO_2 condensed from distillation of cleaning solution in still **258**. Cleaning solution may be transferred to still **258** and distilled to separate the CO_2 solvent from surfactants and contaminates among other things. Cleaning solution is transferred by opening valves **211**, and **218** and starting pump **255**. When the desired amount of cleaning solution has been transferred, pump **255** is secured and valves **210** and **212** are shut. The cleaning solution in still **258** is distilled by opening valve **216**, bringing still **258** on-line. Valve **214** is opened and condenser **251** is brought on-line, then valves **207** and **205** are opened and vapor flows from still **258** through lines **240, 232, 222**, and **227** into condenser **251** where it condenses. Liquid CO_2 then flows through lines **228** and **229** into liquid carbon

dioxide collecting tank **259**. Still another source of liquid CO_2 may be wash tank reflux that occurs when liquid in wash tank **254** is heated by opening valve **215**, bringing heating element **256** on-line. Valve **214** is opened and condenser **251** is brought on-line, then valves **208**, **207**, and **205** are opened. Vapor flows from wash tank **254** through lines **232**, **222**, and **227** into condenser **251** where it condenses. The liquid CO_2 flows through lines **228** and **229** into liquid carbon dioxide collecting tank **259**. Another source of liquid CO2 may be vapor transfer from vapor tank **250** after a system cooling procedure has been performed as described above for the system in Figure 1.

Liquid CO_2 in liquid carbon dioxide collecting tank **259** may be used to rinse clothes in wash tank **254** as follows. Liquid carbon dioxide collecting tank **259** has been filled with liquid CO_2 as described above. A wash cycle, as described above for the system in Figure 1, proceeds through the extraction step. Valves **206**, **205**, and **201** are opened allowing the contents of the liquid carbon dioxide collecting tank **259**, in this case liquid CO_2, to flow through line **231** into wash tank **254**. When the desired amount of liquid CO_2 has been added to wash tank **254**, valves **206**, **205**, and **201** are shut. Clothes in wash tank **254** are contacted with the liquid CO_2 for a sufficient amount of time to rinse any residual cleaning solution from the clothes. The drain and extraction steps described above for the system in Figure 1 are then repeated to remove the rinse solution from wash tank **254**, and the carbon dioxide vapor in wash tank **254** may be removed as described above for the system in Figure 1. Liquid carbon dioxide collecting tank **259** may be refilled by one of the methods described above.

Liquid in liquid carbon dioxide collecting tank **259** may be used to wash filter **257**. One who is skilled in the art will appreciate that the cleaning system could include one or more than one filter in many different configurations. Liquid carbon dioxide collecting tank **259** has been filled with liquid carbon dioxide as described above. A wash of the filter may be performed as a periodic operation. In the preferred embodiment, a wash may be performed on a weekly basis, more preferred for commercial operations at a time when cleaning operations are not scheduled. The filter wash may be initiated by employees as they leave for the day. The cycle would commence and follow a normal wash cycle, as described above for the system in

Figure 1, through the vapor charging step with the exception that no clothes would be added to wash tank **154**. During this time, additives may be added to the liquid CO_2 in liquid carbon dioxide collecting tank **259** through additive injection port **217** to form a filter wash solution. These additives may shift the adsorption equilibrium of adsorbed dyes or other contaminants such that they become soluble in liquid carbon dioxide. The precise additive needed to clean filter **257** will depend on the type of contaminant to be removed from it and will be known to those skilled in the art.. If no additives are added to liquid carbon dioxide collecting tank **259**, the filter wash solution consists of liquid carbon dioxide.

The contents of liquid carbon dioxide collecting tank **259** are added to wash tank **254** by opening valves **206**, **205**, and **201**, allowing the filter wash solution to flow through line **231**. When the desired amount of filter wash solution has been transferred to wash tank **254**, valves **206**, **205**, and **201** are shut. Valves **211**, **218**, and **208** are opened and pump **255** is started. Filter wash solution is circulated from wash tank **254** through lines **235** and **238**, through filter **257**, through lines **239** and **241**, through still **258**, which is off-line, and through lines **240** and **232** back to wash tank **254**. After washing filter **257** for a sufficient amount of time, preferably between about 1 and 600 minutes, most preferably between 1 and 20 minutes, the filter wash solution may be transferred either to working tank **254** or to still **258**. Filter wash solution may be transferred to working tank **254** by shutting valve **208** and opening valves **209**, **201**, and **205**. When wash tank **254** is empty, pump **255** is secured and valves **211**, **218**, **209**, **201**, and **205** are shut. Alternatively, filter wash solution may be transferred from wash tank **254** to still **258** by shutting valve **208**. When wash tank **254** is empty, pump **255** is secured and valves **218** and **211** are shut. Filter **257** may be positioned at an elevation above still **258** so that filter **257** may be drained into still **258** by gravity. The filter wash solution may then be distilled by opening valves **207** and **205**, then opening valves **216** and **214**, bringing the still and the condenser on-line. Vapor from the still travels through lines **240**, **232**, **222**, **227**, condenses in condenser **251**, then liquid carbon dioxide travels through line **228** into liquid carbon dioxide collecting tank **259**. When the contents of still **258** have been distilled, valves **216**, **214**, **207**, and **205** are shut. Carbon dioxide vapor in wash tank **254** may be

removed as described above for the system in Figure 1. Liquid carbon dioxide collecting tank **259** may be refilled by one of the methods described above.

Liquid in liquid carbon dioxide collecting tank **259** may be used to help remove non-volatile residues present on clothes in wash tank **254** after the wash cycle. Liquid carbon dioxide collecting tank **259** has been filled with liquid CO_2 as described above. A wash cycle, as described above for the system in Figure 1, proceeds through the extraction step. Before the vapor removal step, a second extraction step may be performed as follows. Valves **206**, **205**, and **201** are opened allowing the contents of the liquid carbon dioxide collecting tank **259**, in this case liquid CO_2, to flow through line **231** into wash tank **254**. Clothes in wash tank **254** are contacted with the liquid CO_2 for a sufficient amount of time to remove some or all of the remaining non-volatile residues from the clothes. During this time, heating element **256** is brought on-line by opening valve **215**. As the liquid in wash tank **254** boils, the carbon dioxide vapor created condenses on the cooler clothes that are in wash tank **254**, which may extract the residues. The condensed carbon dioxide vapor falls back to the bottom of wash tank **254** and may be reboiled. After this second extraction step has been performed for a sufficient time, heating element **256** is taken off-line by shutting valve **215.** The drain and extraction steps described above for the system in Figure 1 may be repeated to remove the liquid from wash tank **254**. Wash tank **254** may be depressurized as described above for the system in Figure 1. Liquid carbon dioxide collecting tank **259** may be refilled by one of the methods described above.

The present invention may be carried out in an any suitable carbon dioxide dry cleaning apparatus, particularly an apparatus as described in J. McClain et al., copending U.S. Patent Application Serial No. 09/047,013 (filed March 24, 1998); an apparatus as described in J. McClain et al., copending U.S. Patent Application Serial No. 09/306,360 (filed May 6, 1999)(disclosing a preferred direct drive system); an apparatus as disclosed in J. DeYoung et al., copending U.S. Patent Application Serial No. 09/312,556 (filed May 14, 1999); and an apparatus as described in U.S. Patent Application No. 09/405,619 filed concurrently herewith, to McClain et al. entitled *System for the Control of a Carbon Dioxide Cleaning Apparatus* which is commonly

assigned to the assignee of the present invention, the disclosures of all of which is incorporated by reference herein in its entirety.

While the embodiments described above have focused on methods and apparatus for contacting clothes with a liquid carbon dioxide solution, one skilled in the art will appreciate that the methods and apparatus described above could be used for contacting other articles, including but not limited to parts and tools.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.